ARKIV FÖR FYSIK Band 14 nr 25

Communicated 4 June 1958 by H. ALFVÉN and N. HERLOFSON

The latitude effect of the cosmic ray nucleonic component in relation to the magnetic dip

By ARNE ELD SANDSTRÖM

With 4 figures in the text

ABSTRACT

This paper is concerned with data collected by means of an airborne monitor during a flight across the north polar region and around Asia and Europe. Complete records of the primary results together with a discourse on the latitude effect were presented at the international conference on cosmic rays at Varenna, June 1957 (in print). The data have now undergone further treatment. The C R intensity values have been normalized by means of the monitors in Uppsala and on Mt. Norikura and Zugspitze. The differences between the three sets of normalized values turn out to be comparatively unimportant. The latitude effect is studied as a function of the dip. Some discrepancies are discussed as well as the influence of a possible longitude effect. By comparing the geographical coordinates of points of equal C R intensity it is demonstrated that the effective field causing the latitude effect cannot easily be represented by a simple dipole model. Instead the true geomagnetic field, as represented by the dip, appears to be a good first approximation of the field determining the cut off of the primaries. Anomalies can be ascribed to the fact that the tracks of the primaries from being at first determined by a dipole field gradually enter a part of the geomagnetic field differing very little from that at the surface of the earth.

Introduction

From February 16 to 28, 1957 the latitude effect of the cosmic ray nucleonic component was measured during a flight from Stockholm across the north polar region to Alaska and Tokyo returning around the southern parts of Asia and Europe. The cosmic ray intensity was recorded by means of a small neutron monitor. A description of the experimental arrangements and a first account of the results were presented in a paper submitted to the Varenna conference on cosmic rays, June 1957 [1]. This paper contains all primary data corrected to one and the same isobar level. The intensity, plotted as a function of conventional geomagnetic coordinates, exhibits a marked discrepancy between the two branches of the curve starting and ending at the minimum and maximum geomagnetic latitudes (Fig. 1). However, Rothwell and Quenby [2] have shown that the points of minimum cosmic ray intensity follow the 0°-isoclinic (dip equator) rather than either the geomagnetic equator of the conventional dipole model or that of the dipole model proposed by Simpson *et al.* [3].

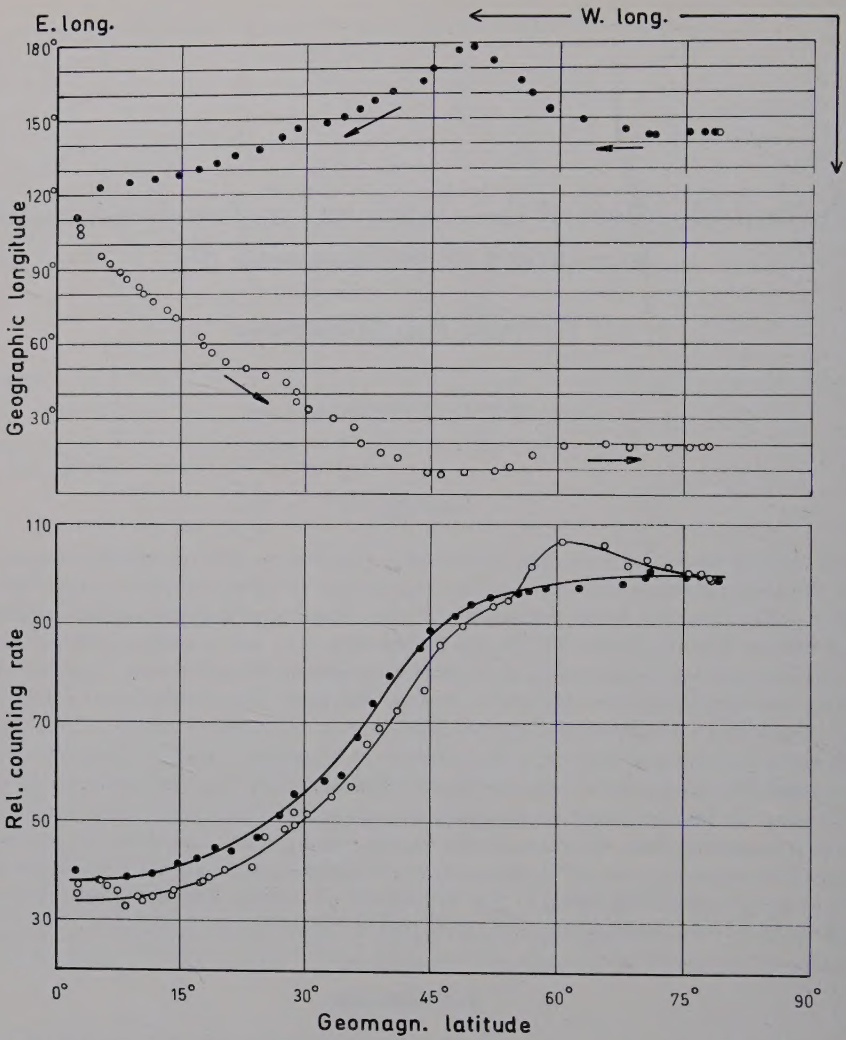

Fig. 1. The not normalized cosmic ray intensity as a function of conventional geomagnetic latitude. The filled circles constitute the eastern branch, the open circles the western branch. The geographic longitude of each point can be read from the upper part of the figure. To avoid congestion some points have been left out in the vicinity of the discontinuous shift from eastern to western longitudes at the North Pole. The arrows indicate the direction of the flight.

Their opinion appears to be supported in part by the results published by Katz, Meyer, and Simpson [4]. Measurements carried out with an airborne monitor by Storey, Fenton, and McCracken point in the same direction [5]. Nevertheless considerable discrepancies still remain, and apparently the "dip model" can only be regarded as a first approximation.

As a consequence of the new viewpoints it has become appropriate to renew the discussion of the results from our own experiences with an airborne monitor. Following the evidence produced it is natural to assume that some of the discrepancy displayed in Fig. 1 will disappear if the variation in cosmic ray intensity is referred to the dip.

Normalization of the primary data

When first published the data were not referred to any standard intensity established by monitors in permanent positions on the ground. At that time data were available from Uppsala and Mt. Norikura, only. Although some changes took place in the level of the particle flow during the time of the flight, these were regarded as too small to affect the results in comparison with other sources of errors. It also appeared doubtful if these two widely separated stations should be used for normalizing the values from the whole round trip. Instead the original values were plotted in the diagrams and smooth curves fitted to the points.

Since the Varenna conference data for the crucial time have also been obtained from Zugspitze. If necessary, normalization can therefore now be made for three latitude regions. How far such a division into regions serves any purpose will be discussed in connection with the diagrams in Fig. 3.

When normalizing data through the medium of fixed monitors it ought to be remembered that the statistical fluctuations of the fixed instrument will be added to those of the transported one. In the present case all three fixed monitors are of the standard type [6] with high counting rates. However, while Zugspitze and Mount Norikura are both situated at a considerable height the Uppsala monitor is at sea level. Matters are complicated by the fact that only one half of the Zugspitze monitor was in working order during the time of the flight. Table 1 contains a survey of counting rates and standard deviations.

The latitude effect and the conventional dipole model

As all necessary details concerning the airborne monitor and the flight itself were given in a previous paper [1] together with an extensive data table both these parts are excluded here. Table 1 gives an idea of the accuracy of the measurements. In only two cases points of measurement were lost owing to trouble with the instrumental equipment. At Anchorage, Alaska, the printing counter stuck as the result of too

Table 1.

Neutron monitor	Height above s.l.	Counts min.	Per cent standard deviation		
			2 hrs period	1 hr period	48 min. period
Uppsala, Sweden	Sea level	410	0.45	0.64	
Zugspitze, W. Germany	2966 m	1930		0.29	
Mt. Norikura, Japan	2840 m	1730	0.22	0.31	
Airborne monitor on DC7C-planes					
Polar region	590 millibar level	210			1.0
At "knee"		180			1.1
Minimum counting rate		70			2.8

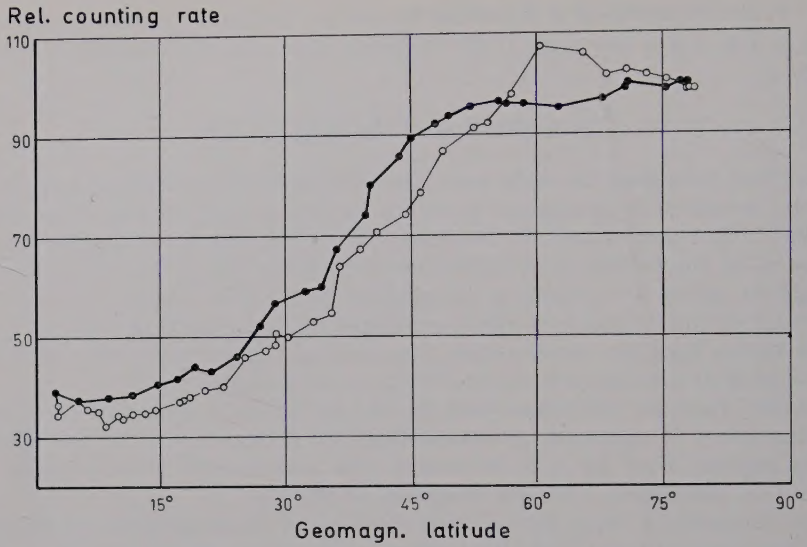

Fig. 2. The cosmic ray intensity, normalized by means of the Uppsala monitor, as a function of conventional geomagnetic latitude. The filled circles constitute the eastern branch, the open circles the western branch.

low a temperature in the cabin. After take off at Manila moisture on some insulators made registrations impossible for nearly one hour. These gaps in the records are not in any way important.

In Fig. 1 the relative cosmic ray intensity is displayed as a function of conventional geomagnetic coordinates. The intensity values are not normalized in this figure. The return flight covered several distances having a considerable extension in the east-west direction. To account for this (also regarding Figs. 2–3) the geographic longitudes are plotted in the upper part of Fig. 1.

As already remarked in the paper presented at the Varenna conference [1] there is a systematic displacement between the points constituting the eastern and western branches of the curves representing the nucleonic component as a function of conventional geomagnetic latitude (Fig. 1). The remarkably high intensity over Northern Europe is not included among these discrepancies. The latter feature will not be discussed in this paper as further investigations are indicated.

The discrepancies do not disappear when the intensity values are normalized. This is very well demonstrated by Fig. 2, which represents the values when normalized by means of the Uppsala monitor. In this figure as well as those following in the next section the representation by continuous curves has been abandoned for the more common representation by polygones. This emphasizes that each point represents the average intensity for a certain interval of time and distance. Comparison with Fig. 3 shows that the discrepancies will remain also when the results are normalized by means of the other two fixed monitors.

The systematic nature of the shift between the two curve branches is slightly more emphasized by the representation in Fig. 2 than by that in Fig. 1. In both cases the "knee" of the western branch is badly defined. Normalization does not shift the positions of the knees outside the rather wide limits of error (Table 2). Disregarding the confusing instance of the abnormally high counting rate characterizing some of the nearby points, both knees certainly appear at the same geomagnetic latitude.

The latitude effect and the dip

In Fig. 3 the relative intensity is plotted as a function of the dip. In the first of the four diagrams the values have not been normalized. The other three illustrate the effect of normalization by means of each of the three fixed neutron monitors available at the time of the flight. The dip values have been obtained from the map "Curves of magnetic dip, 1955" compiled at the Royal Greenwich Observatory.

In all four diagrams of Fig. 3 the eastern and western branches of the curves fit far better than in Fig. 2, where they were referred to conventional geomagnetic coordinates. Some parts can be said to fall almost together, the points of measurement actually becoming mixed. There are really no prominent differences between the three cases of normalization and the diagram of not normalized values. However, there are regions in which all four diagrams display tendencies towards a systematic discrepancy: 20°–40°, 54°–57°, 60°–69°, and 70°–81°. Regardless of normalization to any fixed monitor the discrepancy changes its sign for every alternate region. Accordingly, the first of the regions excepted, these shifts between the two curve branches do not appear to be due to a longitude effect.

A longitude effect will mostly affect the values in the region of low latitudes. Along the "cosmic ray equator" Katz, Meyer, and Simpson [4] have found a considerable longitude effect. In the present case a corresponding effect is to be expected in the longitude region 50° E to 130° E, i.e. dips between 11° and 40°. However, a comparison with the curve published by Katz *et al.* indicates that the curve branch for the eastern part of the flight is moved upwards and the other curve branch moved downwards if the correction for the latitude effect has the same sign in the region in question as along the equator. It looks as though some other effect not only counteracts the longitude effect but overruns it.

In the region 70° E to 103° E there are many instances where the variation with the dip is very small, even parts where there is no variation at all. Nevertheless, throughout this region the course of the aeroplane made finite angles with the dip curves. According to the measurements by Katz *et al.* along the "cosmic ray equator" the longitude effect, if existing, would add to the increase of the cosmic ray intensity with the dip.

It is also impossible to ascribe the deficit in counting rate in this region to any definite systematic error as for example the production of neutrons in the fuel, which would result in the counting rate decreasing with distance flown. That such an error does not enter is shown by the fact that refuelling took place in approximately the middle of the region under discussion without any noticeable and abrupt change of counting rate.

Considering that the four diagrams of Fig. 3 are nearly identical there seems to be no point in dividing the track into latitude regions corresponding to the three reference monitors. The two northern regions would be very narrow as compared to the region referred to Mt. Norikura. The latter would have its reference monitor in its northern part thus making the selection of regions artificial. The same applies to a division of the track according to distance flown. However, if the diagrams of Fig. 3

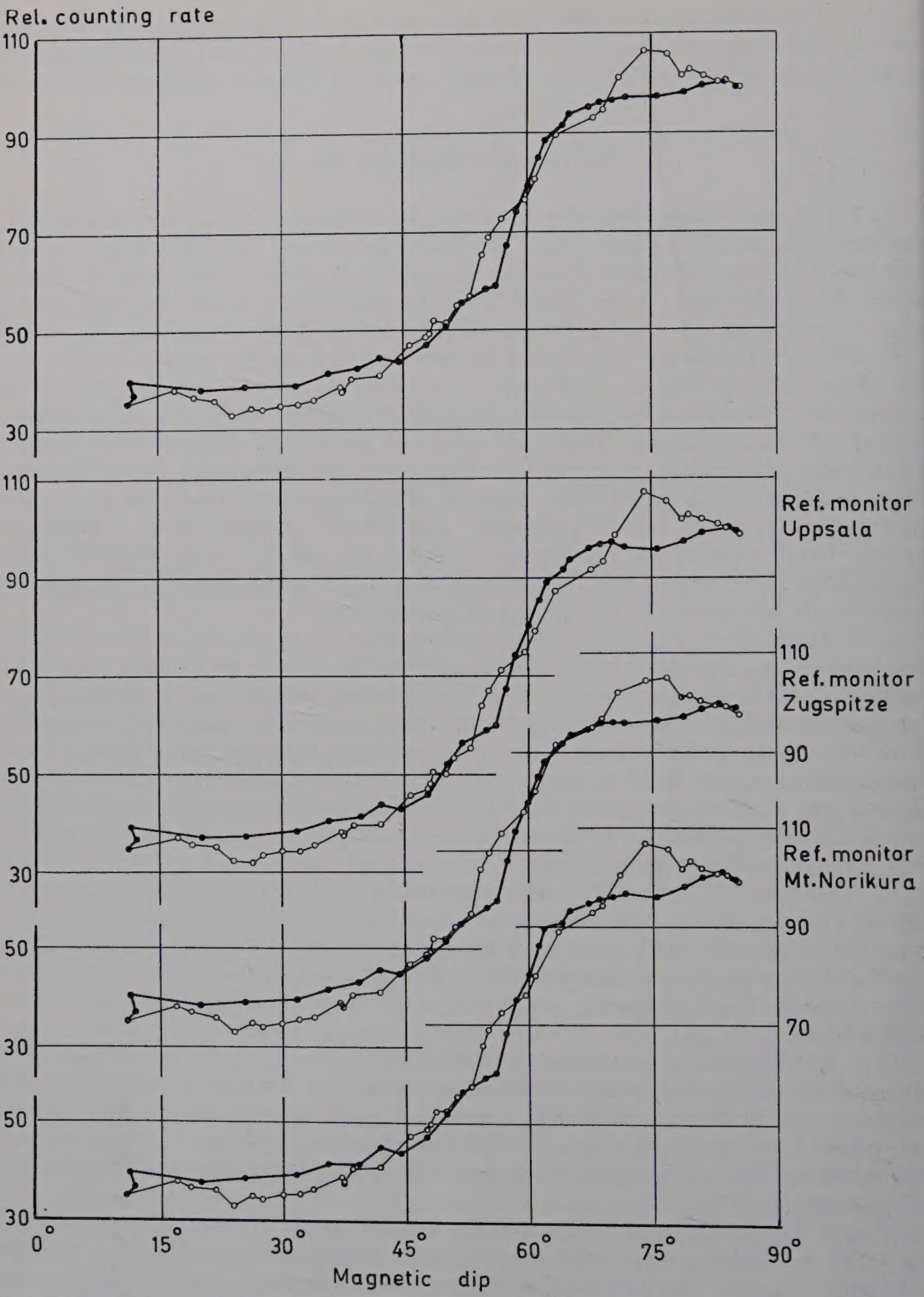

Fig. 3. The cosmic ray intensity as a function of the dip. The upper diagram reproduces the not normalized relative intensities. In the lower diagram the relative intensities have been normalized by means of the contemporary values from the Uppsala, Zugspitze, and Mt. Norikura monitors. The filled circles constitute the eastern branches, the open circles the western branches.

Table 2.

	Conventional geomagnetic lat.		Dip			
	C.R. intensity not normalized	C.R. intensity normalized to the Uppsala monitor	C.R. intensity not normalized	C.R. intensity normalized to the Uppsala monitor	C.R. intensity normalized to the Zugspitze monitor	C.R. intensity normalized to the Mt. Norikura monitor
Eastern knee	51° ± 2°	51° ± 2°	63° ± 2°	63° ± 2°	63° ± 2°	64° ± 2°
Western knee	49° ± 2°	48° ± 2°	63° ± 2°	63° ± 2°	63° ± 2°	62° ± 2°

are placed one upon the other it turns out that the eastern branches can be brought to fall fairly close together while the western branches display variations according to the reference monitor employed. This indicates the existence of local variations in the data from the fixed monitors during the later stages of the return flight. It follows that the Zugspitze monitor ought to be employed for reference during the flight across Central Europe. This brings the two curve branches very close together just around the "knee".

Owing to the continuous change of the slope the knees are never sharply defined. Even when this is disregarded the four diagrams in Fig. 3 show the knees of the two curve branches at one and the same dip (Table 2).

By comparing Fig. 3 to Fig. 2 it becomes evident that as a first approximation it is far better to refer the cosmic ray latitude effect to the dip than to conventional geomagnetic coordinates. The variation of the dip with geographic latitudes has such a character that it will scarcely be possible to approximate reality just by turning the conventional dipole model a certain number of degrees around the earth's axis as proposed by Simpson [3].

Points of equal cosmic ray intensity

It is of interest to study the relative position of points of equal cosmic ray intensity. Unfortunately a single loop around the world does not offer a sufficient number of such points for the construction of isocosms i.e. curves of equal primary cosmic ray intensity [7]. We are therefore restricted to comparing the relative positions of pairs of points only.

In Fig. 4 the geographic latitudes of points of equal cosmic ray intensity are plotted against their longitudes. To make it possible to identify points forming a pair all pairs are joined by straight lines representing chords through the earth. A couple of exceptions are to be noted in the southernmost part of the flight, where in two cases four points of equal intensity could be found. The points are to be regarded only as examples. They all correspond to points in the diagrams Figs. 1 to 3 (values listed in Table 1 in the paper presented at the Varenna conference [1]). The relative intensities employed as identification marks in Fig. 4 are approximate averages of the values referred to the three fixed monitors. It is doubtful how the normalized values in general ought to be compiled for a study of the points of equal cosmic ray intensity. Therefore the points in Fig. 4 have been carefully selected among data where the

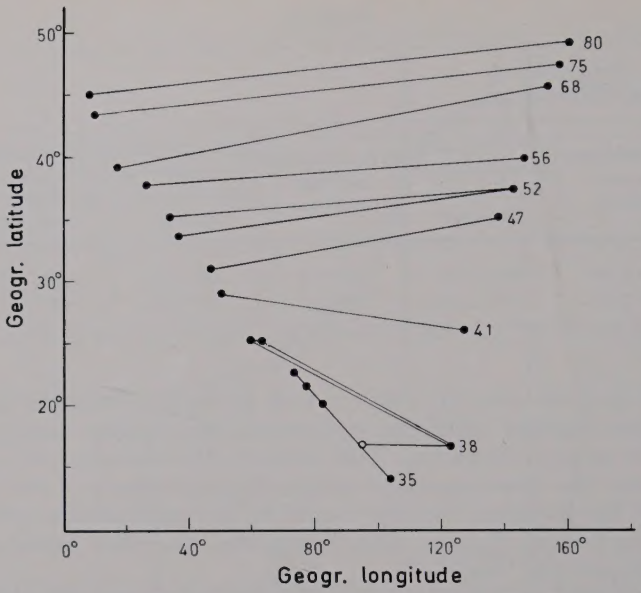

Fig. 4. The distribution in geographic coordinates of points of equal cosmic ray intensity. Approximate values of the relative intensities have been introduced opposite to the eastern points in the diagram. For value 38 there exists a point falling on the line joining the points of relative intensity 35. To distinguish this point from those of intensity 35 it is represented by an open circle.

differences between the three sets of normalized values are too small to interfere with the impression given by the figure.

Had the latitude effect been determined by ideal dipole conditions it ought to be possible to fit a family of parallel planes to the points of equal intensity. As can be gathered from Fig. 4 this is impossible. When judging the angles between the lines in this figure it is necessary to remember that the lengths of these lines do not indicate the order of magnitude of the distances between the points of equal intensity. Thus the distance through the earth between the points marked 80 is only 10 per cent longer than the distance between those marked 41.

As is to be expected the relative positions of the points of equal cosmic ray intensity appear to be more regular in high latitudes than in the neighbourhood of the equatorial region. Especially the two cases with four points of equal intensity indicate considerable distortions.

Conclusion

As a consequence of recent results it now appears to be an established fact that a close correlation exists between the dip and the latitude effect of the nucleonic component. This is contrary to the assumption that the field of the earth can be regarded as a dipole field where cosmic rays are concerned. At present only three explanations suggest themselves for discussion.

I: A considerable part of the latitude effect could be due to the action of the earth's magnetic field upon the secondaries. Lately this problem has once again been thoroughly analysed by Brunberg, who found that the effect will be negligible.[1] Accordingly this explanation has to be abandoned.

II: The irregularities in the magnetic field of the earth are recognizable very much farther out than has so far been supposed. We know from terella experiments [8] that the particle orbits in the earth's magnetic field asymptotically turn into the initial trajectories of the primaries at a distance of the order of magnitude of three times the radius of the earth. Although this is not a big distance as compared to the dimensions of the earth as a magnet it has generally been assumed that far inside this limit the field has the characteristics of a dipole field. If this is not the case it is conceivable that primaries with a momentum just short of the cut off travel quite a long distance through a field reflecting the characteristics of the geomagnetic field close to the surface of the earth.

III: As the production of the secondaries takes place below the 30000 m level, particles with a momentum just below the cut off might travel down to the neighbourhood of this level. In such a case it becomes probable that the cut off is determined by the field in a region inside a comparatively very short distance from the earth's surface.

Any one of the last two explanations appears to fit the fact that it is possible to describe the field determining the latitude effect by means of the dip. However, it is scarcely probable that the local anomalies of the geomagnetic field manifest themselves as far out in space as is necessary for the first of the last two explanations to be valid.

Thus it seems advisable to resort to the last of the three explanations although at first it appears to demand a close correlation between the latitude effect and the dip. However, the primaries are first subjected to the action of an undistorted field before gradually entering a region of perturbations. Accordingly the dip will furnish a first approximation only. Discrepancies are to be expected just as is shown by the results from the flight around Asia and Europe.

The present paper deals only with the correlation between the latitude effect and the dip. It is possible that a modified dipole model can be found which fits the results as well [9]. It is more probable, however, that terms of a higher order have to be introduced. The most rational procedure would be to carry out a harmonic analysis of cosmic ray intensity measurements distributed around the whole earth. The data available at present are insufficient in number for such an analysis. The registrations ought to be made with one and the same monitor or with monitors carefully checked one against the other.

The investigation presented in this paper is part of a cosmic ray project sponsored by the Swedish Natural Science Research Council and the Swedish National Committee for Geodesy and Geophysics. The necessary data could not have been collected if the Scandinavian Airlines System had not opened their new polar route to Tokyo at a very convenient time. I am very grateful to them and to their directors for the permission to make measurements on the preinauguration flight across the North Pole as well as on the return inauguration flight to Europe. I also thank their technicians for the perfect installation of the monitor in both planes.

In collecting the data during the flight I was assisted by Mr. Ole Edvardsen from this laboratory and Mr. Sten Lyholm of the SAS company. I take the opportunity to thank them for their help. I also wish to thank Prof. Y. Miyazaki for the data from the Mt. Norikura monitor and Dr. B Meyer for those from Zugspitze.

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Tryckt den 27 november 1958

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